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DEVELOPMENT OF AN INERTIAL SENSOR-BASED METHODOLOGY FOR SPACESUITED LUNAR GEOLOGY TASK ASSESSMENTS*

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Motivation

- *Apollo Spacesuits*
  - Designed to provide a life-sustaining environment during extravehicular activities (EVAs)
  - Geological sampling had to be performed in a standing posture due to inflexibility of the pressurized spacesuits
    - 67% of fall-related events occurred during sample collection or equipment interaction[1]
    - Apollo astronauts reported that kneeling to collect surface samples should be considered for future Lunar spacesuits possessing greater flexibility[2]

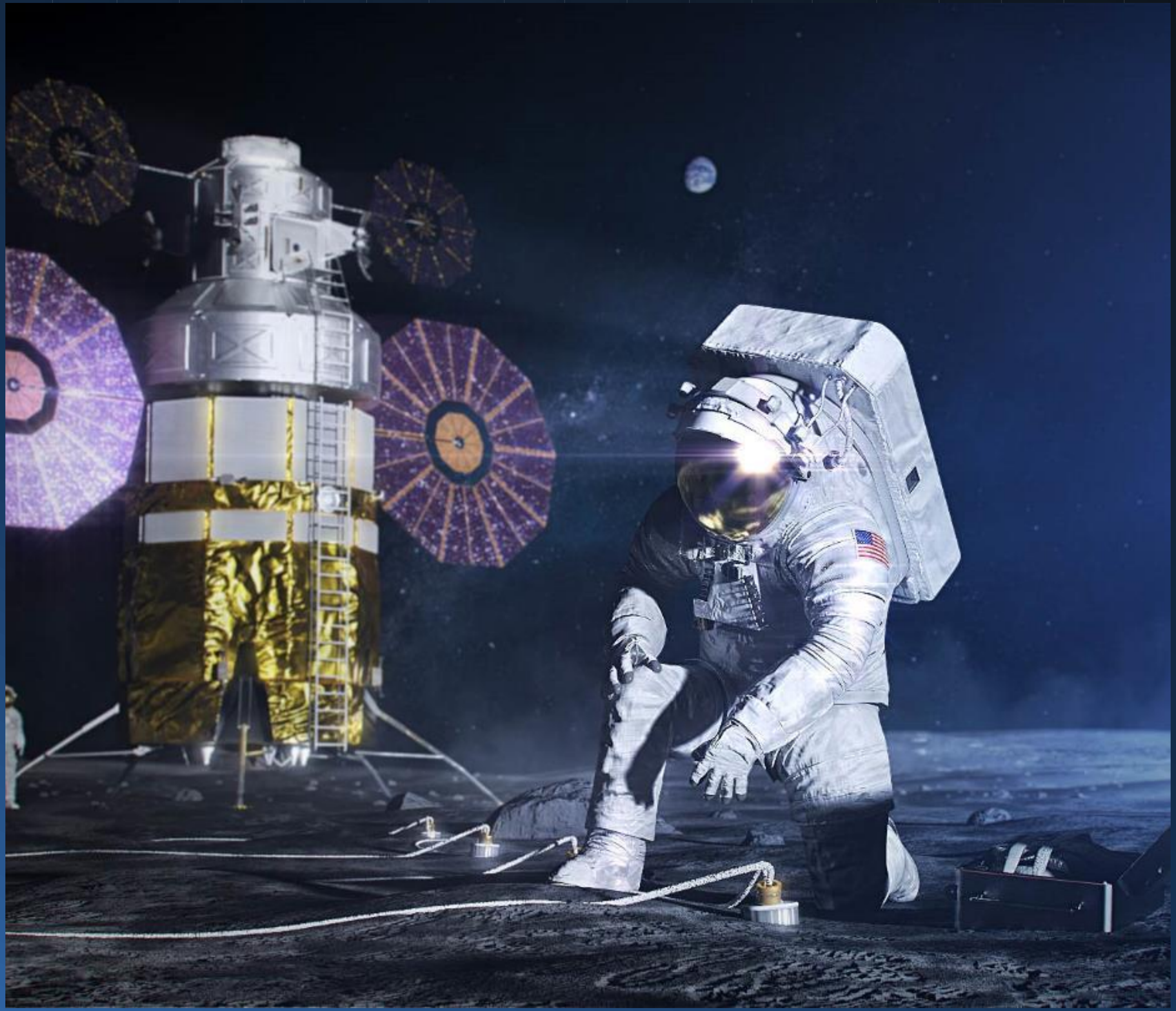
*Apollo 17 astronaut Harrison Schmitt collecting a soil sample (Credit: NASA)

1. Thuro, A. and Stirling, L., "Characterization of the Apollo Astronaut Lunar EVA Falls and Near-Falls," IEEE Aerospace Conference, 2021.
2. Graves, "Apollo experience report: Mission planning for Apollo entry," NASA TM, 1972.

Motivation

- *Next-Generation Spacesuits*
  - Expected to incorporate advanced materials and joint bearings allowing for greater mobility and a wider range of postures
  - Will allow for standing, squatting, and kneeling postures during Artemis EVAs
  - Artemis missions will likely have more frequent EVAs on complex Lunar terrains that require a larger range of functional postures.

<u>Research question 1.</u> Are Artemis crewmembers at a higher risk of back or leg injuries during planetary surface EVAs compared to 0-g EVAs?



*A Next-generation spacesuit for the Artemis astronauts (Credit: NASA).

Motivation

- *Geologic Training*
  - Should be designed to reduce injury risk and enhance productivity as well as learning geological activities

Research question 2: How can we quantitatively evaluate postures during geology tasks to identify task-related injury risk?

  - Untrained or newly trained people have been observed to perform motions differently than trained individuals

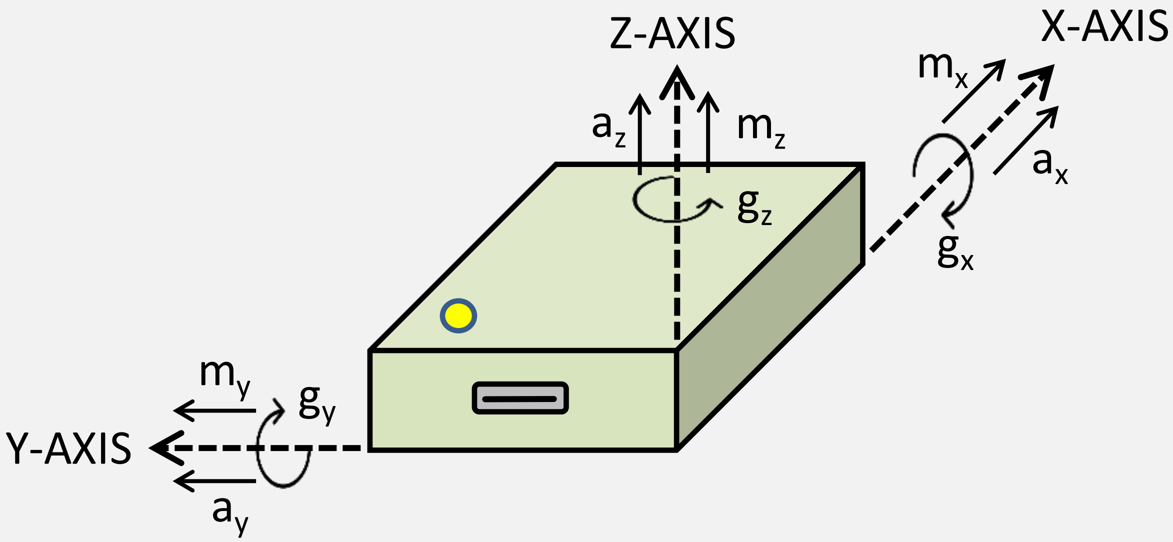
Research question 3: Is there any preferred posture in professional geologists during geology tasks?

* Simulated geology task during D-RATS (Desert Research and Technology Studies). (Credit: H-3PO Lab)

Introduction

- *Inertial Measurement Unit (IMU) Motion Capture*
  - Wearable motion capture systems that use portable IMUs
  - We have been conducting engineering evaluations using IMUs to advance the current understanding of the capabilities and characteristics of next-generation spacesuits and EVA training facilities[1-5]
  - The proper combination of the number and location of IMUs has the potential to prevent the consequences by guiding the correction of sustained poor posture.

IMU:

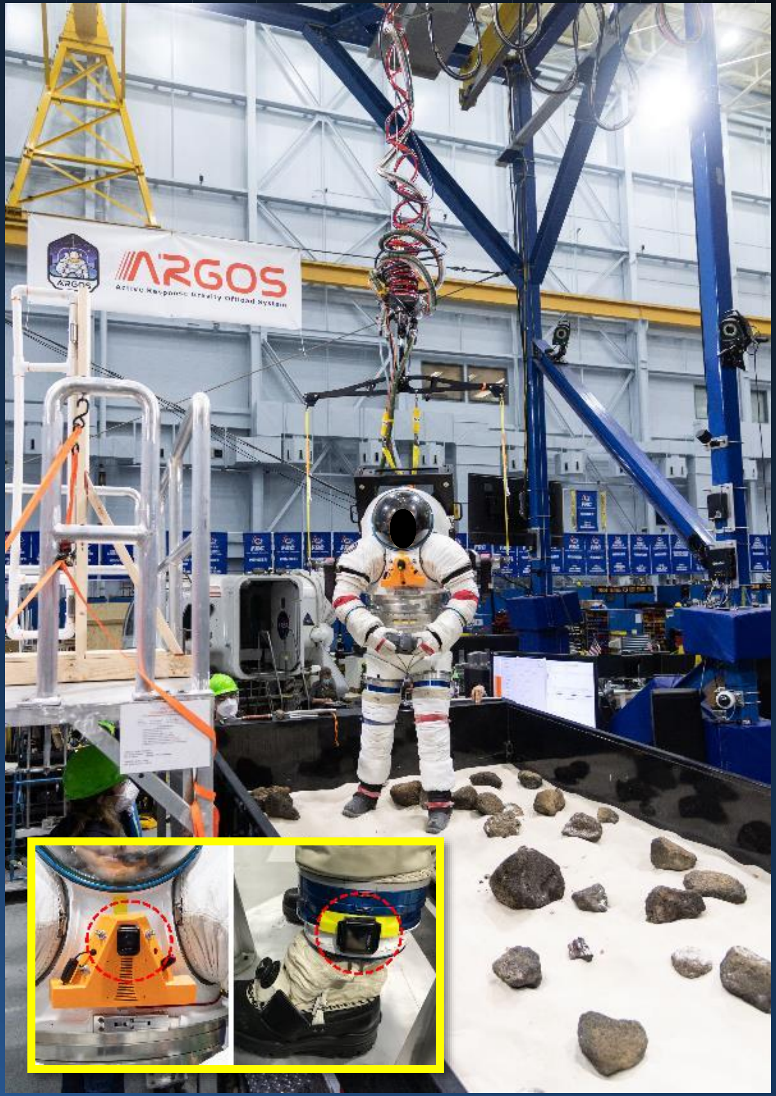


- 3-axis accelerometer (linear acceleration: a_x, a_y, a_z)
- 3-axis gyroscope (rotation rate: g_x, g_y, g_z)
- 3-axis magnetometer (magnetic field: m_x, m_y, m_z)

1. Kim, et al., "Characterization of Activities and Postures during Planetary EVAs via Inertial Measurement Units," ASB, 2020.
2. Kim, et al., "A Comparison of Gait Characteristics between EVA Training Environments," ASB, 2020.
3. Bekdash, et al., "Development and Evaluation of the Active Response Gravity Offload System as a Lunar and Martian EVA Simulation Environment," ICES, 2020.
4. Kim, et al., "The Instrumented Walking and Turning Test to Evaluate Space-suited Gait Dynamics and Performance in EVA Training Environments," ISPGR, 2022.
5. Baughman, et al., "Assessments of Physiology And Cognition in Hybrid-reality Environments (APACHE)–Physical Workload Approximation," ICES, 2022.

Methods

- *Subjects*
  - Two healthy male subjects with prior spacesuit testing experience in partial-gravity environments
    - One professional geologist (20+ years of geology experience)
    - One non-geologist
- *Test Setup*
  - Mark III prototype planetary spacesuit
    - Large-size Hard Upper Torso (HUT)
    - Leg module for each subject:
      - Geologist (height 188 cm): Large extra long legs + 1.2'' upper leg sizing ring and 1.2'' lower leg sizing ring
      - Non-geologist (height 181 cm): Large extra long legs + 0.6'' upper leg sizing ring
    - Three wireless IMUs (APDM Opal, OR, USA)
      - 1 chest, 2 ankle bearings (120 Hz)
  - Active Response Gravity Offload System (ARGOS)
    - Set to simulate the 1/6-g environment
    - A trailer used to simulate surface geology



(Credit: H-3PO Lab)

Methods

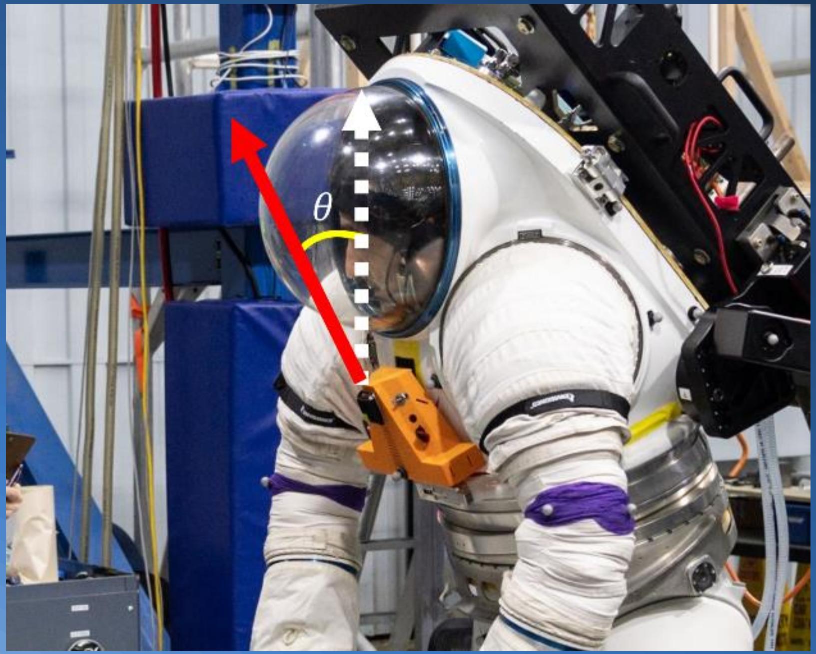
- *Geology Tasks*
  - Standalone task circuit (end-to-end sampling with individual tools to capture the functional movements)

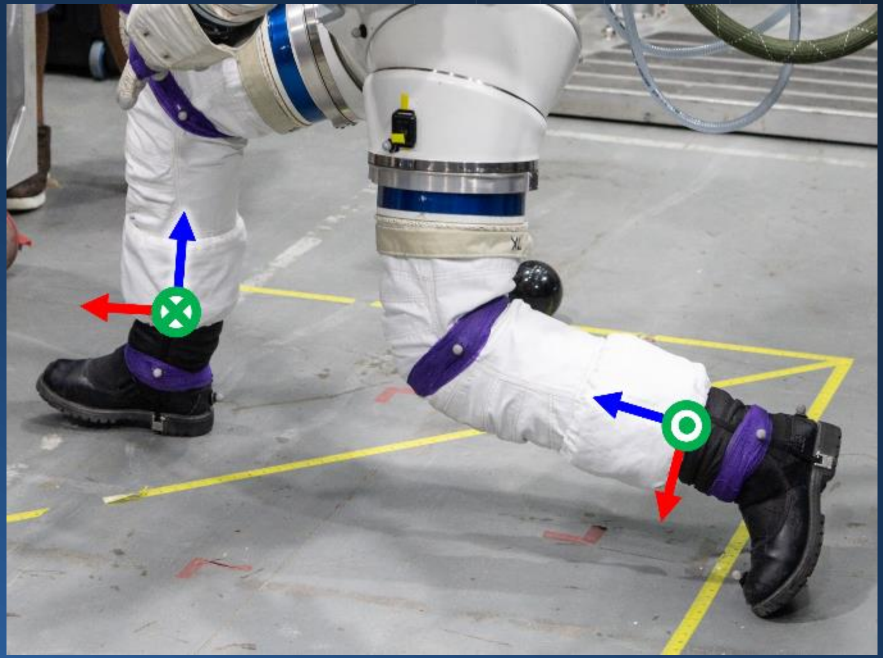
Task	Time (min)
Drive Tube	5
Rest	2
Rake	5
Rest	2
Stand trench	5
Rest	2
Hammer/Chisel	5
Rest	2
Kneel Scoop	5
Rest	2
Sample Tag	5
Planned total time	35

(Credit: H-3PO Lab)

Methods

- *Data Processing*
  - Upper body tilt angle
    - Chest IMU data fused into quaternions and transformed into Euler angles[1]
  - Posture classification
    - The ankle IMUs discriminated standing and kneeling using the absolute value of the amplitude of the blue axis component and a support vector machine[2,3]





(Credit: H-3PO Lab)

1. Madgwick, et al., "Estimation of IMU and MARG orientation using a gradient descent algorithm," IEEE Int. Conf. Rehabil. Robot., 2011.
2. Kim, et al., "Characterization of Activities and Postures during Planetary EVAs via Inertial Measurement Units," ASB, 2020.
3. Cristianini and Shawe-Taylor, "An Introduction to Support Vector Machines and Other Kernel-Based Learning Methods," Cambridge Univ. Press, 2000.

Results

- *Posture & Upper Body Tilt Angle*
  - Absolute and relative time in standing and kneeling postures during geology tasks:

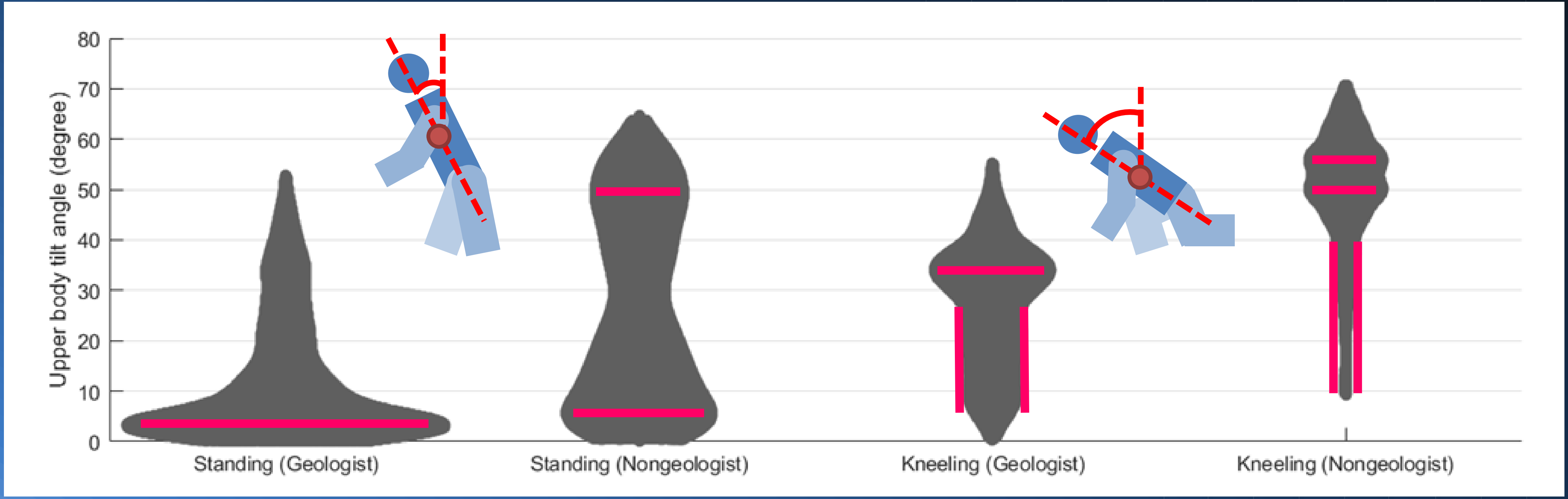
Time (min)	Total	Standing	Kneeling
Geologist	45	27 (61%)	18 (39%)
Non-geologist	41	32 (77%)	9 (23%)

  - Upper body tilt angle during standing and kneeling activities:

Upper body tilt angle (degree)	Geologist Standing	Non-geologist Standing	Geologist Kneeling	Non-geologist Kneeling
Min	0	0	0.4	9.4
Max	52.7	64.7	55.1	70.7
Q(0.25)	2.9	8.3	18.1	46.5
Q(0.50)	6.4	22.9	29.6	52.4
Q(0.75)	17.9	45.1	35.4	57.3
Mean	11.9	26.8	27.0	51.3

Results

- *Swarm Scatter Chart of Upper Body Tilt Angles*



  - The geologist subject maintained a relatively lower range of upper body tilt angle both while standing and kneeling; the non-geologist subject showed more variation of the torso tilt angle and preferred bending the upper body rather than changing from standing to kneeling posture and vice versa.

Discussion

- Poor posture may lead to more rapid fatigue, higher injury risk, and possibly even premature termination of the EVA
  - *Obtaining knowledge of the motion characteristics and differences between subjects can be a starting point to track suited injuries during missions.*

- A more upright pose was observed in the geologist during standing activities. The geologist's standing time within 0–20 degrees was 77%, while the non-geologist's time was 46%
  - *This might suggest that the geologist subject was inclined to increase stability and minimize straining his back in the standing posture during geology.*

- The geologist spent 16% longer in the kneeling posture
  - *This finding is likely because the geologist was trained to kneel frequently and maintain more stable and efficient postures while sampling. The non-geologist maintained the stooping posture with a greater torso tilt angle rather than changing from standing to kneeling posture.*

Limitations & Future Work

- Our results are currently limited to two subjects and thus should not be generalized to the astronaut population or applied to NASA standard measures.

- The non-geologist subject may not have the same working geology knowledge to perform the rock sample inspections and actions as the geologist subject.

- The trailer to simulate surface geology in this study was a confined area to perform the complete EVA circuit.

- Future work should include subjects with different anthropometric characteristics (various spacesuit sizes) and different ARGOS offloading configurations as these can have significant impact on suited task performance.

- Future work will expand the proposed wearable system to support the real-time use application.
  - Real-time visualization and feedback using the frontend software will evaluate postures during geology tasks to identify or prevent task-related injury risk.

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- *Suited Subjects*

(Credit: H-3PO Lab)

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